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Engineering Cost Studies[1]

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Introduction

THE subject assigned to me in the "Notes Regarding the Program of the Conference" is "The Theoretical Principles of Economic Studies and Their Possible Application in Undergraduate Courses." With your permission, I shall digress somewhat from a literal consideration of this title. I shall not undertake to derive formulae, to set up equations and to obtain maxima and minima from them. The mathematics can readily be obtained from available sources. On the other hand, I shall attempt to outline the field for economic studies in engineering work, using illustrations drawn from telephone engineering practice.

What is an engineering cost study? When you or I reach a decision to purchase a certain pair of shoes, making a selection from an assortment ranging in price from (say) $5 to $15, we have performed, consciously or unconsciously, some of the reasoning of an engineering cost study. Among the factors influencing our decision will be the probable length of service life of different pairs, as well as the ability to extend this by an expenditure, to be made at some future time, for maintenance as represented by new soles and heels, which, perhaps, can be applied economically to a moderately costly pair but not so to the cheapest.

These two elements, depreciation and current maintenance, are factors entering into engineering cost studies but they are not all of the factors. Whether we have the necessary capital in hand, or are obliged to hire or otherwise raise it, the annual cost of the capital must be taken into consideration, and treatment of the matter of depreciation is incomplete without consideration of salvage value and cost of removal.

Thus, unless we pursue our investigation into details that are not ordinarily considered when buying shoes, it is evident that our

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homely illustration, while serving to center our attention on certain important subjects to be taken up in this paper, falls short in respect of others that can not be neglected in engineering cost studies. Broadly speaking, engineering cost studies deal with the comparative annual costs of alternative projects. Frequently they also involve comparisons of expenditures to be made at different times in the future. They are of value to industrial executives in assisting them to arrive at decisions where several courses of action are open, but they are not the sole guides in arriving at decisions. No hard and fast formulae can take the place of judgment based on experience. Formulae of this nature are properly used as guides to assist judgment.

The necessity for guidance from studies of this kind arises most frequently in a growing plant. The telephone plant always has been, and so far as we can anticipate, will continue to be a rapidly growing thing.

This means that whenever an addition is to be made, the question arises, how much capacity for growth is it most economical to provide for? As an illustration of this, consider with me the problem that arises when it becomes necessary to place somewhere an underground cable. Obviously it would be uneconomical to construct an underground conduit of one duct for this cable and next year or the year after to dig up the street and lay another duct for a second cable and so on in piecemeal, hand-to-mouth fashion.

On the other hand, it would not be economical to estimate the number of cables that would be required in a hundred years, even if we could foresee the needs so far ahead with any degree of certainty, and to place at the outset sufficient ducts to care for all the cables required along that route in the next century, for in that event, the carrying charges on the idle ducts would prove much more expensive, in the long run, than would additions made at infrequent intermediate times. Somewhere between one year and one hundred years is the most economical period for which to provide duct capacity in advance. The determination of this period, based on suitable construction costs, the expected rate of growth in cable requirements, and other factors is one of the useful results obtained from an engineering cost study.

Under our organization, practically all types of plant and equipment are developed by the Central Staff. These are standardized in a range of sizes sufficient to meet all the needs of the business.

The choice of standards and sizes to meet specific situations arising

in the field is made by the proper officials of the associated operating companies.

If a piece of apparatus or equipment, correctly designed within itself, is installed in the wrong place, or if a wrong size is selected, loss will result.

Questions of where to place plant and what size to employ, and when to replace existing plant constantly confront the operating engineers in the field. In the telephone business every major construction project is described in what we term an "estimate" which is nothing more or less than a detailed design for the project, embodied in drawings and specifications, accompanied by a carefully prepared estimate of its cost. These estimates originate in the Plant Departments of the Associated Companies and are really the bids of the construction forces for performing the work. These estimates pass through the hands of the Chief Engineer of the Associated Company for his scrutiny and approval before they proceed to the higher officials of that company for final authorization. The Chief Engineer considers these estimates in their relation to the general plans of the Company with reference to the growth of the business and the plant. For many years the chief of the Department of which I am a member, Vice President General John J. Carty, occupied the post of Chief Engineer of the New York Telephone Company, the largest associated company of the Bell System. I have heard him say that when, while occupying that position, an estimate for some specific piece of work came before him for review, he asked himself three questions regarding it:

1. Why do it at all?
2. Why do it now?
3. Why do it this way?

Rigorous proof sufficient to answer these three questions will justify the endorsement of any engineering project, and, furthermore, each question generally involves an engineering cost study.

Fundamental Plans

Of all the engineering cost studies that are made in connection with the telephone industry, none is more far-reaching in its effect than those involved in what we term our "fundamental plans." In order to give a fair idea of the importance of the work done under our fundamental plans, it will be necessary to describe briefly what a fundamental plan is.

In completed form a fundamental plan shows what the general lay-out of the telephone plant in a city is expected to be at some definite time, usually from 15 to 20 years in the future. It shows:

(a) The number of central office districts that will be required to provide the telephone service most economically, and the boundaries of these central office districts.

(b) The number of subscribers' lines to be served by each central office.

(c) The proper location for the central office in each district to enable the service to be given most economically with regard to costs of cable plant, land, buildings and other factors.

(d) The proper streets and alleys in which to build underground conduits in order to result in a comprehensive, consistent and economical distributing system reaching every city block to be served by underground cable.

(e) The most economical number of ducts to provide in each conduit run as it is built.

These are all very definite problems that confront the executives of our Associated Companies when plant extensions are required. Our experience has shown that our fundamental plans reduce guessing to a minimum by utilizing the experience of years in studying questions of telephone growth in order to make careful forecasts on the best possible engineering basis. A few words as to how fundamental plans are made may not be out of place.

The basis of the fundamental plan is what we term a commercial survey, which is a forecast of the future community showing the probable amount, distribution and character of the population and the probable market for various classes of telephone service.

Before making this forecast, it is important to know what are the present conditions as to population and use of the telephone service. To ascertain these facts a census of the community from a telephone point of view is made. Present telephone users are classified into:

Residence Telephones.
Business Telephones in Residence Areas.
Telephones in Business Section.

In analyzing Residence telephones all families are divided among those occupying:

(a) Private Residences.
(b) Two-family Houses.

(c) Apartments.
(d) Lodging Houses.

In each class, subdivisions are made according to the rent paid as it has been found that a close relation exists between rent and the class of telephone service used. Business telephones are divided into 20 or 30 different classes. An important factor in the forecast is the future population of the city, both as a whole and by sections.

This involves, in each particular problem, not only study of the past growth of the city in question, but also careful and detailed comparisons with the growth history of other cities where conditions have been such that the experience in those places is useful in making the prediction for the city being studied.

Having arrived at forecasts, for certain future dates, as to the number of telephone users to be provided for, where they will be located, what character of service they will require, what time of day they will call, and how frequently, and where they will call, it becomes a definite, although intricate engineering problem to determine the most economical number, size and location of buildings and switchboards and the location and size of conduit runs. All of the promising combinations of future offices and districts as indicated by experience and the geographical characteristics of the city, are laid out on working maps and the annual costs are figured. The arrangement which gives the lowest equated annual costs over the period of time for which the study is made is, in general, the one which is adopted. Fundamental plans are reviewed every few years, particularly when some major plant addition, for example, the opening of a new central office, comes up for consideration. In this way we are constantly looking ahead and following a coordinated plan; but this plan is not a rigid, fixed thing. It is modified as frequently as may be necessary to meet the constantly changing requirements. In work of this kind, future expenditures must be given greater or less weight accordingly as they are required to be made in the near future or at some more distant time. This is taken into account by equating future expenditures in terms of their present worth; that is, the sum in hand, at the present time, which, at compound interest, will be just sufficient to provide for the future expenditures when they are required.

Transmission Standards and Studies

An interesting and typical annual cost problem which arises in connection with fundamental plans is that of obtaining a proper cost

balance between the circuits employed for subscribers' loops and those employed in interoffice trunk lines. The larger the wire, the better will be the talk. But it will also be more expensive. The first step in solving this problem is to decide how good the transmission must be to afford satisfactory service to the telephone using public. Our present standards are a matter of growth; the accumulated results of long and extensive experience. They are live, working standards constantly being intelligently scrutinized and, when necessary, modified. A discussion of the values of the standards employed would unduly prolong this paper. Therefore, let it suffice, at this time, to state that the telephone offices in a large city, including its environs, may be divided into metropolitan offices and suburban offices; that is, the central business offices separated from the suburban residential offices. Between subscribers in different districts suitable standards of transmission are decided upon.

Before describing this study further, reference must be made to the practical necessity for the standardization of construction materials. Subscribers' loops run in length from a few hundred feet to 3, 4 or 5 miles. If we tried theoretically to make all talks exactly equal in loudness, we should have as many different sizes of wire in our cables as there are different lengths of loop. To reduce the complexity, our cable conductors are of certain standard sizes, which experience has shown are sufficiently close together to meet the needs of the business. These standard sizes, in American Wire Gauge, are Nos. 24, 22, 19, 16, 13 and 10; the three latter not being used in subscribers' loops.

Having adopted standards of transmission and standards of cable conductor sizes, our problem is to obtain the standards of transmission with the standards of cable conductors in the most economical manner.

The method of doing this, in brief, is to figure out the annual costs which would be incurred in doing it a number of different ways and to select the way that gives the lowest annual cost. In this kind of a study, which we call a "loop and trunk" study, it has been convenient to designate the subscribers' loops by their maximum circuit resistance. Adopting this form of designation, it may be assumed, first, that all of the subscribers' loops will have an average transmitting and receiving efficiency as good or better than a 350-ohm loop; as a second assumption, that they will be as good or better than a 400-ohm loop; and, as third and fourth assumptions, 450 and 500-ohm loops, respectively. In assuming, for example, a 350-ohm loop in

No. 24-gauge cable, it is, of course, necessary that all subscribers having loops longer than the amount of No. 24-gauge cable represented by this resistance shall be put in No. 22-gauge or No. 19-gauge cable as may be required.

The transmission losses, both transmitting and receiving, are then computed for the assumed loops. The transmission losses in central office apparatus are constant and known. Subtracting the losses in the offices and in the substation loops for each assumed grade of loop from the transmission standards, leaves the amount of transmission loss which can be allowed in the interoffice trunks corresponding to each limiting grade of subscriber's loop. On the basis of this allowable transmission loss in the trunks and knowing the distances between central offices, we are enabled to fix the size of conductor required in the trunks.

Knowing the grade of loops and trunks required for each of the above assumptions, we can then compute the total annual charge of giving service according to that assumption. If the assumptions have been wisely chosen it will usually work out that the first assumption, that is, a very high grade of subscriber's loop, will not be as economical as some others, due to the relatively high cost of the subscribers' loops taken as a whole. Neither will the last assumption, that is, a very low grade of subscriber's loop, be the most economical, on account of the relatively high cost of the trunks. Somewhere between, however, there will be some assumption which will show the smallest total annual charge.

To find more precisely the most economical arrangement, the various values are plotted with the assumptions as to subscribers' loops forming one set of ordinates and the total annual cost forming the other. The point on the curve representing the lowest annual cost then indicates the proper grade of subscribers' loops to employ. In the case of the longer interoffice trunks, loading is, of course, employed. In the design of toll lines and toll switching trunks generally similar cost balancing methods are employed.

In many cases, the problem can be solved by the determination of what we term "the warranted annual charge" of transmission which may be defined as the annual cost of improving the talking efficiency of the circuit in the cheapest way by a definite small amount. By means of studies of this kind, we obtain a plant closely approximating a balanced cost condition. That is, in such a plant, a dollar can be spent in improving transmission efficiency, no more effectively in one part than in another.

Other Applications of Engineering Cost Studies

From what has already been said, it should not be inferred that the sole application of engineering cost studies is in connection with the problems arising in the operating field. The question whether or not a more efficient piece of apparatus at a higher cost is warranted enters into most of our development problems. The economics of the case lie at the root of our development work in all portions of the plant.

At this point I should like to call attention to the fact that our development work covers not only what are termed "transmission" matters, but also very important problems in switchboards, outside plant and other phases of the business.

The service which we provide is a *communication* service, which involves important problems affecting the means for connecting and disconnecting the parties as well as those other important problems, to which your attention has been particularly directed, relating to the loudness and quality of the transmitted speech.

In cable design, particularly in the case of intercity cables and interoffice trunk cables, the average separation between wires in the cable affects the electrostatic capacity of the circuits and there is a definite capacity which represents the most economical degree of concentration of the wires in the cross-section of the cable. The spacing and inductance of loading coils presents another problem in balanced costs. Even in the case of wooden poles we make use of economic cost studies.

The length of life of a pole depends upon a variety of factors, the most important of which are the character of the timber; whether or not a preservative treatment is employed and, if so, the nature of the treatment; the local climatic and soil conditions and the original size of the pole.

The strength of a pole varies with the cube of the diameter of the sound wood at the weakest section. If the original size of the pole is only slightly more than the critical size at which replacement should be made, the life of the pole will be very short, as decay will reduce the size at the ground line to the critical size within a few years. On the other hand, a pole of huge size at the ground line would have a very long life before rotting sufficiently to require replacement, but the first cost of so stout a pole might readily be so great that its annual cost would exceed that of a smaller and cheaper pole. In our specifications for poles we have constantly

to bear in mind that the elimination of poles containing timber defects of one kind or another means that we are adding something to the first cost of our poles and the criterion must always be whether or not the elimination of these defects will sufficiently prolong the life of the poles to warrant the increased first cost.

There have now been placed before you several examples of problems occurring in the telephone industry in the solution of which engineering cost studies may be advantageously employed, and, probably, enough has been said to make clear the importance of this form of economic analysis.

Factors Entering into Annual Costs and Their Evaluation

Let us now consider together the principal factors entering into annual cost, and how, in the course of our work, we evaluate them.

The several factors are these:

1. Cost of money.
2. Taxes.
3. Insurance.
4. Depreciation.
5. Current Maintenance.
6. Administration.
7. Operating Costs.

Cost of Money. The operating companies of the Bell System obtain the new money that they use in extensions to their plants from the sale of their capital stock and securities—bonds and notes. Such a return must be paid the investor, by the Company, as will induce a constant flow of new capital into the business. This steady influx of new capital is required because the System can not decline to expand. It is obligated to meet the increasing needs of the public it serves. Its need for new capital is a direct result of public demand for the service it renders. The rates for service which public utilities may charge are regulated by the commissions, but neither the commissions nor the utilities can fix the worth of money. Public utilities must pay the cost of money just as they must pay the cost of labor, poles and other material. No investor can be forced to invest. If the rate is below what money is worth in the general money market, he will keep out. Utility companies must bring their offerings to a general money market and submit them, in open competition, with

the offerings of undertakings of every kind requiring capital. There are two ways of getting new money:

1. From investors willing to lend. These are the bond and note holders.
2. From investors willing to become partners in ownership. These are the stockholders.

Not only do stockholders expect a higher return than bond and note holders, but if the stockholders' earnings are insufficient, the bond investor will take his money to some safer market. Taking into account the ratio which must be prudently maintained between funded debt and stock, a proper figure should be obtained as representing the average annual cost of money. This figure should not be confused with the figure that represents a fair rate of return including a margin for surplus and contingencies.

Taxes. Taxes are levied by various governmental bodies, municipal, county, state and federal, on many different bases. In some specific plant problems, taxes have to be computed to meet the conditions of the case at hand but, in general, it is sufficient to employ a percentage charge for taxes based upon the average experience.

Insurance. In the case of buildings, and equipment contained in buildings, an annual cost item to cover insurance should be included.

Depreciation. Depreciation may be defined as the using up of property in service from all causes. These causes include:

(a) Wear and tear, not covered by current repairs.
(b) Obsolescence.
(c) Inadequacy.
(d) Public Requirements.
(e) Extraordinary Casualties.

All telephone property, except land, is subject to deterioration, and the continued consumption of the investment is a part of the cost of the service which must be provided for by charges against earnings. Only a small portion of the plant actually wears out in service. Instances of this are the rotting of poles and the rusting of iron wire, a relatively small amount of which is used in the plant.

On the other hand, it has been the history of the telephone business that enormous amounts of plant have been taken out of service through no defect in their physical condition but either because they had become obsolete through the development of some more economical or efficient type of equipment, or because they had become inadequate to serve the growing needs of the business.

An example of obsolescence is the replacement of antiquated methods of distribution by more modern types. Examples of inadequacy are the replacement of open wires by cable, and the replacement of small cables by larger ones. Examples of public requirement are the abandonment of pole lines and their replacement by underground construction due to road improvements, and the rebuilding of sections of underground conduit due to changes in the grade of streets or to the construction of transit subways. Examples of extraordinary casualties are fires, sleet storms and tornadoes.

The annual charge for depreciation is an amount which, if entered in operating expenses each year during the service life of a unit of plant, would, at the end of that service life, yield a sum equal to the total depreciation of that unit; that is, its first cost in place less the net salvage obtained at its removal. The consumption of capital is a necessary part of the cost of furnishing service and must be provided for by charges against earnings during the life of the property. In arriving at this depreciation charge the best thing we can do is to take our experience of years and look over the whole situation and apply our judgment to it. The value of this judgment depends on the experience, knowledge, ability and integrity of the people who exercise it.

The amount of this charge should be determined for each broad class of plant and it depends upon the average service life and the net salvage value. Net salvage value is gross salvage value minus cost of removal, and takes into consideration both value for reuse and junk value. For instance, the net salvage value of station apparatus is relatively high because a large part of the equipment can be reused in another location. In other cases, such as iron wire, the net salvage value may be a minus quantity, as there is little or nothing to offset the cost of removal.

Current Maintenance. Current maintenance charges comprise the cost of repairs, rearrangements and changes necessary to keep the plant in an efficient operating condition during its service life. In cost studies, current maintenance charges should be derived from experience and expressed, generally, on a unit of plant basis, as. for example, per pole, per mile of wire, per foot of cable, or per station, according to the kind of plant being considered. Generally speaking, they bear no direct relation to first cost of plant as other annual charges do.

For this reason, when comparing the annual costs of two or more plant units of different sizes or types, an incorrect result would be

obtained if maintenance charges were expressed as a percentage of the first cost.

However, for comparative cost studies of average plant, maintained under average conditions, it is sometimes within the precision of the study to employ figures expressed as a percentage of the first cost, provided the figures were derived from the cost of maintaining average plant where average conditions were known to obtain.

Administration. In certain cost studies, a small allowance is usually made to cover that portion of the salaries and expenses of the general officials of the Company which is fairly chargeable to the administration of the plant.

Operating Costs. In certain classes of engineering cost studies, comparisons may involve the situation where one type of plant costs initially more than an alternative type, but permits savings to be made in the daily operating labor which may or may not offset the additional first cost. In such cases, to obtain a true comparison, the operating labor costs under each plan must be combined with the total annual charges which are applied to the first costs of the respective plant quantities.

Present Worths

Engineering cost studies frequently involve a balance between plant installed at the present time and plant installed at some future time. An example of this would be the comparison of a pole whose life was to be extended by attaching it to a stub after (say) 15 years, with a stouter and more expensive pole installed at present or with a pole to which preservative treatment was applied prior to its installation.

In such cases it is not sufficient to compare annual costs which are to be incurred at different times without reducing them to a basis upon which they can properly be compared. If a given amount is required to be expended at some future time, it obviously requires a smaller sum at present in hand to meet this obligation if the fixed time is far distant than if it is in the immediate future.

Let us picture ourselves at the end of the year 1924. If an annual charge of $1,000 is to be paid each year for the 5 years beginning January 1, 1925 and ending December 31, 1929, there will be required, to provide for these five $1,000 payments, the sum of $4,100, in hand, assuming that interest is compounded annually at 7 per cent. On the other hand, if these five annual payments of $1,000 each instead

of beginning in 1925 were to begin ten years later, that is, if they were to run from January 1, 1935 to the end of 1939, we should require, in hand, $2,084, that is, only about half as much.

To compare, upon a fair basis, expenditures that have to be made at different times, it is customary, as has been done in the preceding example, to reduce these different expenditures to their "Present Worths," or the equivalent in equated or accumulated annual charges.

Summary

From all that has been said, it becomes evident that, whenever a specific addition is made to a growing plant, we are, to a greater or less extent, committing ourselves to a definite programme for relieving, reinforcing or replacing it at some future time in order most economically to provide for the requirements of growth.

The underlying thought, which can not be overemphasized, is so to plan the plant that, as far as practicable, it will serve for its full life, and require no wholesale changes involving the abandonment of substantial portions of the installation. While the design should be based upon the best estimates of future growth that are obtainable, it must be recognized that the most carefully designed plant layouts employing the best possible estimates of growth, may not always meet the ultimate requirements of flexibility. The chances of a comprehensive plan not fitting in with future development can, however, be reduced to a minimum by thoughtful initial planning.

Generally speaking, our distributing plant layout, once it is established, can not readily nor economically be materially changed. Consequently, if it is not sufficiently flexible in the fundamentals of its design to meet reasonable future possibilities, it may affect adversely the carrying out of proper and economical relief measures, or may require abnormally early reconstruction or replacement. It is very desirable, therefore, always to keep in mind, in any plant layout work, the progressive relief steps which are likely to be required to meet the changing conditions affecting the service requirements. Whenever plant is moved, or taken out of service, property loss is realized. Certain expenditures for these purposes represent the most economical way of conducting the business. But it is of the utmost importance that they should always be incurred along the line of maximum economy, which means that behind every plant

addition must be engineering cost studies to assist in furnishing the answers to the three questions:

Why do it at all?
Why do it now?
Why do it this way?

But it must always be borne in mind that these studies do not and can not, in themselves, constitute the sole criterion for determining what should be done. They are, at the best, only an aid, guide and check to be utilized, within their limitations, in arriving at conclusions that must, in the last analysis, rest upon seasoned judgment and experience.

Nevertheless, so great do we find the importance of these engineering cost studies in our work, and so great must be their importance in the engineering of any other kind of growing plant, that the question might be raised whether, in courses of engineering instruction, a few hours at least could not advantageously be devoted to acquainting the student with the nature and importance of these economic problems.